Study of the Martian boundary layer, mountain meteorology and 2001 dust storm with the LMD Mesoscale Model

Aymeric Spiga[1], François Forget[1] and Luca Montabone[1], [1]Laboratoire de Météorologie Dynamique, Université Pierre et Marie Curie, F-75005, Paris, France (spiga@lmd.jussieu.fr)

Model The LMD Mesoscale Model is a new versatile simulator of the Martian atmosphere and environment at horizontal scales ranging from 100s km to 10s m (see [1] for a complete description). The model combines the NCEP-NCAR fully compressible nonhydrostatic ARW-WRF dynamical core [2], adapted to Mars, with the LMD-GCM comprehensive set of physical parameterizations for the Martian dust, CO_2, water and photochemistry cycles [3]. Since LMD-GCM large-scale simulations are also used to drive the mesoscale model at the boundaries of the chosen domain of interest, a high level of downscaling consistency is reached.

Validation Used in synoptic-scale mode with cyclic domain wrapped around the planet, the LMD Mesoscale Model correctly replicates the main large-scale thermal structure and the zonally-propagating waves. The model diagnostics of near-surface pressure, wind and temperature daily cycles in Chryse Planitia are in accordance with the Viking and Pathfinder measurements [4]. Afternoon gustiness at the respective landing sites is correctly accounted for on the condition that the convective adjustment is turned off in the mesoscale simulations. On the rims of Valles Marineris, intense daytime anabatic (~ 30 m.s^{-1}) and nighttime katabatic (~ 40 m.s^{-1}) are predicted [5]. The correct altitude of the Tharsis topographical water ice clouds in the afternoon are reproduced by the model [6].

LES and convective vortices Through Large-Eddy Simulations in Gusev Crater, the model accurately describes the mixing layer growth during the afternoon and the associated dynamics [7, 8] : convective motions, overlying gravity waves and numerous dust devil-like vortices (figure 1). Agreement between the modeled temperature profiles and the miniTES measurements [9] is satisfactory. LES were also carried out with dust available for lifting and advection by the convective vortices.

Olympus Mons nighttime "warm ring" A nighttime "warm ring" at the feet of Olympus Mons is identified in the simulations, resulting from adiabatic warming by the intense downslope winds along the rims of the volcano (figure 2). Through thermal IR forcing by the overlying atmosphere, the surface temperature enhancement reaches $+20$ K all night long. Such a phenomena may have altered the thermal inertia measurements in the region [10].

Elysium Mons wake Intense wake circulation takes place in Elysium Planitia when the northern fall jet-stream blows on the giant Elysium Mons volcano (figure 3). Non-linear phenomena [11] occurs in the lee of the volcano with distinct dynamical regimes between night and day. The daytime flow is characterized by flow splitting and moderate trapped lee wave activity : vortices appear on the flanks of the volcan as the flow passes around the obstacle. The nighttime flow is characterized by strong gravity wave activity, as a significant part of the incoming flow passes over the obstacle, leading to an extended hydraulic jump in the lee of the volcano where vortices are generated. The role of the anabatic and katabatic circulation might be crucial to account for this "switching" between two distinct dynamical regimes.

2001 dust storm LMD Mesocale Model simulations were carried out in Terra Tyrrhena and Hesperia Planum to study the onset of the 2001 "global" dust storm. Initial and boundary conditions for the mesoscale model are extracted from UK Martian GCM "TES data assimilation" simulations [12] ; the dust opacity evolution during the simulation is derived from TES measurements as well.

By the end of the afternoon, figure 4 shows both 1) enhanced near-surface wind stress (and therefore, enhanced dust lifting) northern of Hellas and southern of Isidis, and 2) updrafts in Terra Tyrrhena resulting from the convergence of the anabatic winds emerging from the two craters, while a few days before both the vertical and horizontal winds were much less intense. These two phenomena acts as a positive feedback for a rising dust storm in the region. They are associated to the thermal tide pressure minimum, which position could in turn be modified by the dust injected in the atmosphere [12].

This encouraging preliminary step needs to be completed by further simulations : grid nesting and finer resolution to better resolve the vertical motions; advected dust particles instead of prescribed TES dust opacity; interannual comparison with conditions where regional dust storms are taking place in the Hellas region without leading to a planet-encircling dust storm.

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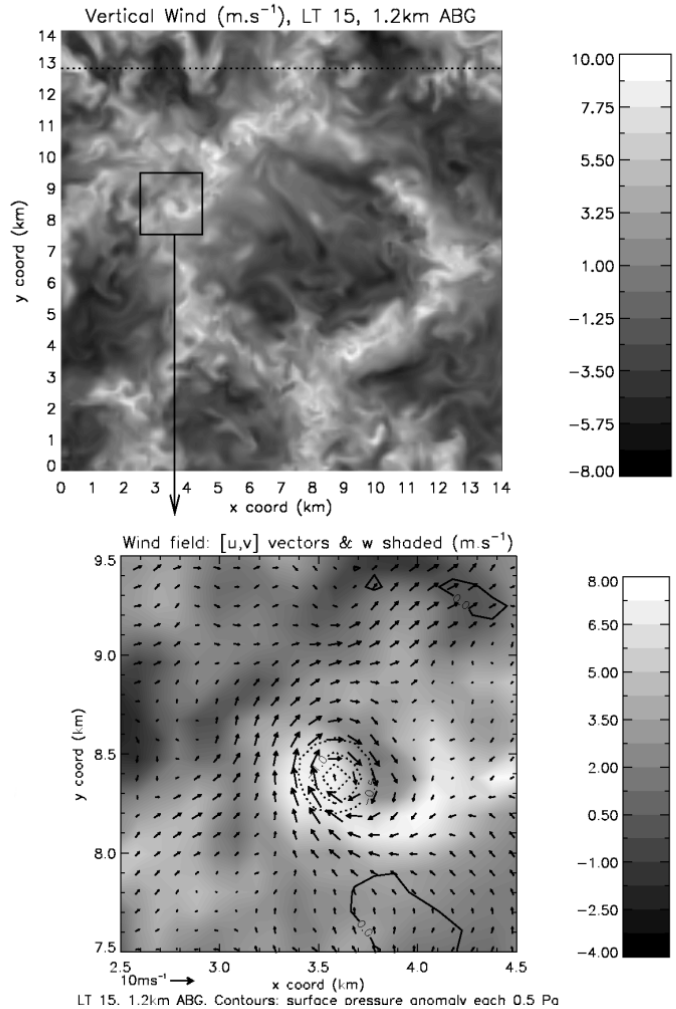

Figure 1: **LES and convective vortices**. Horizontal resolution is 100 m, model top is 250 Pa, L_s is $2.5°$. [TOP] Vertical velocity horizontal section 1.2 km above the surface, on the entire simulation domain (located in Gusev Crater). Local time is 0300PM. Updrafts are represented in white; downdrafts in black. Each kilometer comprises 10 grid points, enabling a fine representation of the "large eddy" part of the turbulence spectra, as could be observed in the figures. [BOTTOM] Enhanced view of a particular vortical structure of the TOP figure (B&W scale is different) forming at the intersection of the polygonal convective cells. Horizontal wind vectors are superimposed, as well as contours corresponding to the surface pressure anomaly (0.5 Pa spacing). Maximal depression in the vortex core is ~ 1.5 Pa.

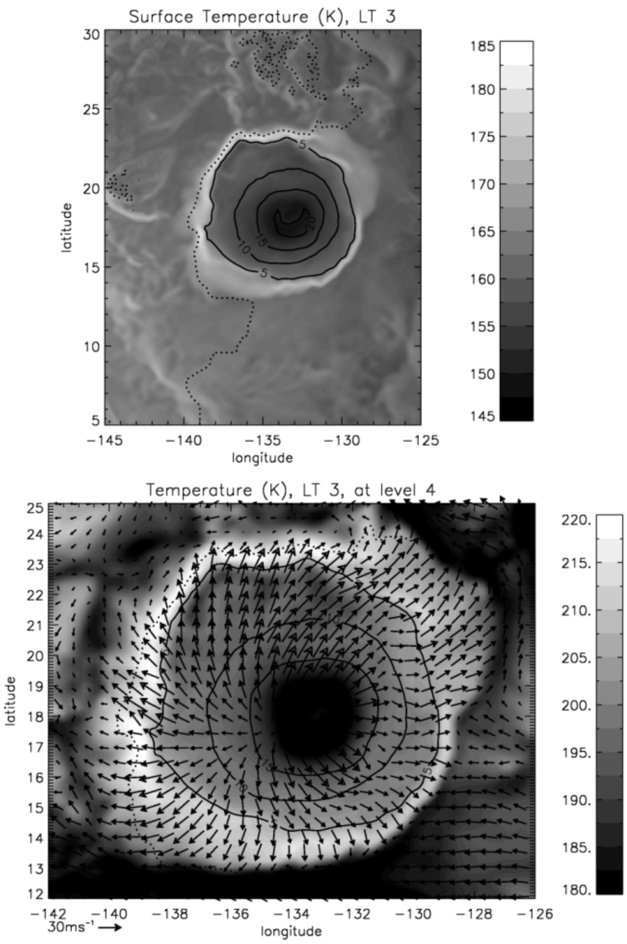

Figure 2: **Olympus Mons nighttime "warm ring"**. Horizontal resolution is 10 km, model top is 3 Pa, L_s is 175°. Simulations are carried out with constant thermal inertia of 85 J m^{-2} K^{-1} s$^{-0.5}$. [TOP] Surface temperature at local time 0300AM. Warmer temperatures are white. Topographic contours are superimposed for reference (altitudes -2.5, 5, 10, 15, 20, 25 km). [BOTTOM] Atmospheric temperature in the 4th model level ($\sim$ 120 m above the surface). Horizontal wind vectors are superimposed every 3 grid points. Maximum horizontal wind velocity at this level is $\sim$ 40 m.s^{-1} (above Olympus caldeira). Warmer temperatures are white, and topographic reference is the same as the TOP plot.

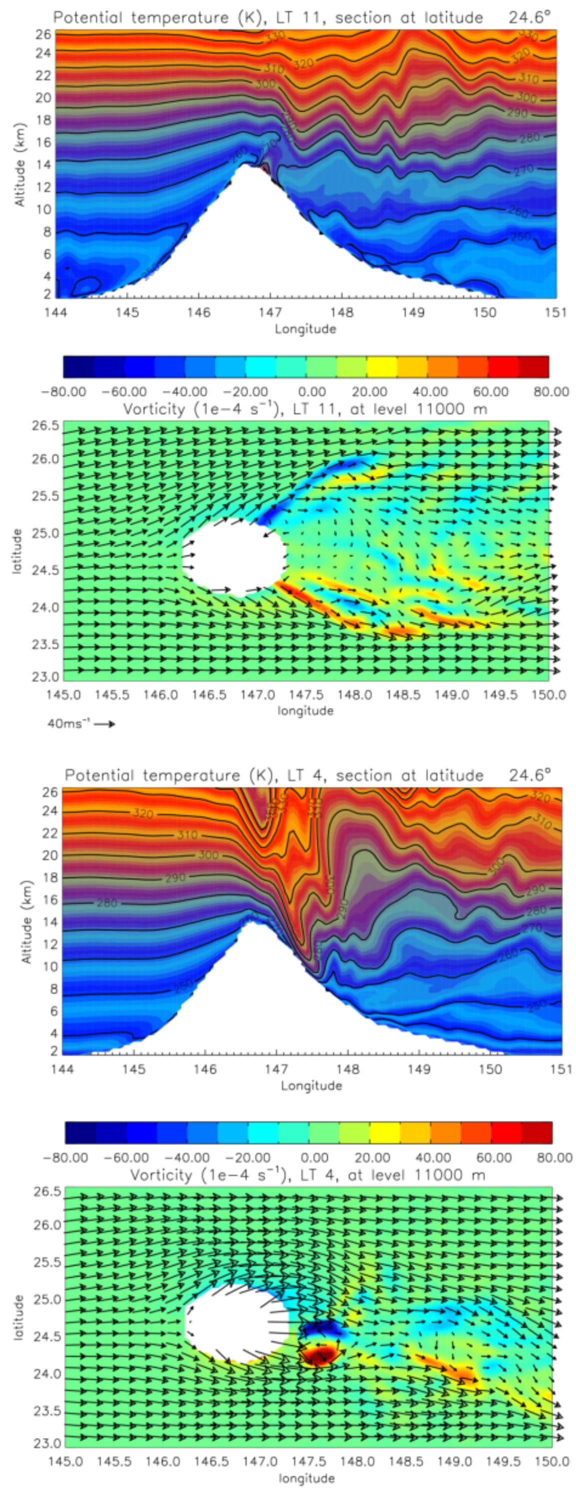

Figure 3: **Elysium Mons wake**. Horizontal resolution is 3 km (third nested domain), model top is 3 Pa (~ 45 km), L_s is $181°$. [P1] Altitude/longitude cross-section of potential temperature (K) with contours superimposed every 10 K. Local time is 1100AM. Oscillations eastward of the volcano correspond to trapped lee waves of moderate amplitude. [P2] Horizontal section of relative vorticity ($10^{-4}\mathrm{s}^{-1}$) at the altitude 11 km with wind vectors superimposed every three grid points. Vorticity is generated in the flanks of Elysium by flow splitting around the volcano. [P3-P4] Same as [P1-P2] except that local time is 0400AM. Vorticity is generated in the lee of Elysium by hydraulic jump discontinuity (potential temperature folding and abrupt flow deceleration) over the volcano.

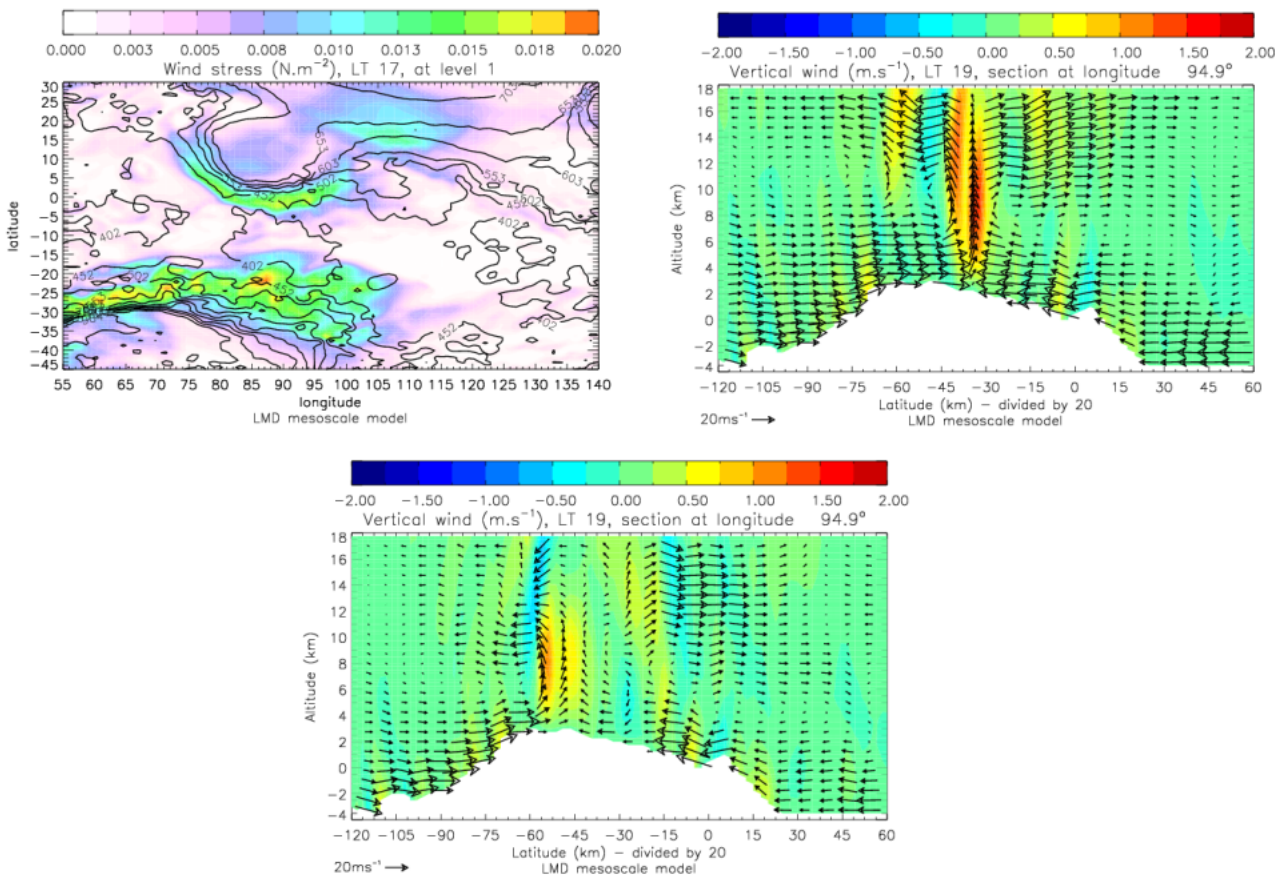

Figure 4: **2001 dust storm**. Horizontal resolution is 50 km, model top is 2 Pa. [TOP] (left) Near-surface wind stress (N m^{-2}) at local time 0500PM and $L_s \sim 185°$ (sol 380, $\tau \sim 1.5$ in Terra Tyrrhena). Surface pressure contours are superimposed to indicate the topography. (right) Latitude/altitude cross-section of vertical velocity (m s^{-1}) with wind vectors superimposed every 3 grid points (vertical scale is exaggerated by a factor of 20 – scaling of vectors is thus altered). Local time is 0700PM. [BOTTOM] Same as top-left but at $L_s \sim 179°$ (sol 371), when the injection of dust in the atmosphere is moderate ($\tau \sim 0.3$).